Scope of Work For

Project #20-020
New Satellite Tools to Evaluate Emission Inventories:
Is a 3-D Model Necessary?

Prepared for

Air Quality Research Program (AQRP)
The University of Texas at Austin

By

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Version #1

QA Requirements: Audits of Data Quality: 10% Required
Report of QA Findings: Required in Final Report

NOTE: The workplan package consists of three independent documents: Scope of Work, Quality Assurance Project Plan (QAPP), and budget and justification.

Approvals

This Scope of Work was approved electronically on **06/10/20** by Elena McDonald-Buller, The University of Texas at Austin

Elena McDonald-Buller
Project Manager, Texas Air Quality Research Program

This Scope of Work was approved electronically on **06/19/20** by Mark Muldoon, Texas Commission on Environmental Quality

Mark Muldoon
Project Liaison, Texas Commission on Environmental Quality

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1.0 Abstract

This study will develop best-practice recommendations for the utilization of satellite data for emissions evaluation. Because of their radiative properties, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are among of a small group of gas-phase air pollutants that may be reliably detected from space. These gases have short atmospheric lifetimes, such that satellite-based observations are a useful an indicator of fuel combustion. Although the characterization of gas-phase emissions has emerged as one of the leading areas for air quality utilization of satellite data, multiple atmospheric processes affect the relationship between satellite-derived column abundance and near surface. We will evaluate two different methods to compare satellite NO_2, and to a limited extent SO_2, with emission inventories developed by the Texas Commission on Environmental Quality (TCEQ).

Our proposal directly responds to two Priority Research Areas for the Air Quality Research Program (AQRP): the use of remote sensing for (1) point source and (2) county-level emissions. We will develop methods to leverage remote sensing capabilities to improve emission inventories, without undermining the process-based nature of the inventories, essential for their use in air quality management.

These methods include:

1) Comparison of satellite-derived NO_2 and SO_2 from TROPOMI for summer 2019 with model simulations from a WRF-CAMx modeling system developed for the TCEQ;

2) Simpler approaches to comparing NO_X emissions and TROPOMI data that don't require a photochemical grid model, especially the Exponentially Modified Gaussian (EMG) approach. These simpler methods will be extended to SO_2 as resources and data integrity allow. These analyses will focus on 2019, but include a brief comparison with 2020 TROPOMI data as well. Because TROPOMI data for 2020 reflects actual conditions, it will provide some information on the change in emissions associated with the social and economic response to COVID-19.

This analysis will evaluate methods by which high-resolution satellite may be compared with emissions inventories, and to assess the necessity of computationally intensive modeling approaches. Study goals include the validation of the TCEQ 2020 modeling inventory (including the value of alternate methods to calculate on-road mobile emissions), as well as recommendations and software to support future TCEQ utilization of satellite data for emission evaluation. Results emerging from the proposed study will be submitted as a manuscript for peer-reviewed publication. (Note that the TCEQ 2020 inventory we will assess is based on a projection from historical data, so it does not reflect actual 2020 conditions associated with broad social and economic response to COVID-19).

2.0 Background

Air quality management in Texas, like other states, is closely linked with accurate emission inventories. These inventories quantify chemical release into the atmosphere from identified sources, and are used as the basis of regulatory decision-making, atmospheric modeling, and assessment of trends. Although continuous emissions monitoring systems (CEMs) measure power plant emissions directly, most other emission sources are calculated based on ancillary data and assumptions, such as vehicle activity and land use. As such, there is some uncertainty in the accuracy of existing emission inventories, and potential for satellite remote sensing to evaluate and improve inventory development.

Because of their radiative properties, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are among of a small group of gas-phase air pollutants that may be reliably detected from satellite instruments [*Richter and Burrows*, 2002; *Richter et al.*, 2005; *Martin*, 2008; *Duncan et al.*, 2014]. With relatively short atmospheric lifetimes, satellite-based observations of NO_2 have been found useful as an indicator of fossil fuel combustion, and satellite-based observations of SO_2 have been found useful as an indicator of coal combustion [*Streets et al.*, 2014]. Spatial and temporal patterns in atmospheric NO_2 and SO_2 columns have been shown to reflect spatial variation, day-to-day and year-to-year changes in emissions of NO_X and SO_2 [e.g. *Martin*, 2003; *Lamsal et al.*, 2011; *Mijling and Van Der A*, 2012; *Tong et al.*, 2016].

Over the past few years, major advances have occurred in the integration of satellite data with air quality planning [*Holloway et al.*, 2018]. Characterization of gas-phase emissions has emerged as one of the leading areas for air quality utilization of satellite data from the National Aeronautic and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and satellites launched by international space agencies. Although satellite data bear relevance to emissions characterization, atmospheric processes including boundary layer mixing, dispersion by winds, and photochemistry affect the relationship between satellite-derived column abundance and near surface emissions [e.g. *Harkey, Holloway et al.*, 2015]. Additionally, the once-a-day snapshot provided by current-generation polar-orbiting satellites must account for the temporal variability in emissions, and processes may affect the column with a delay from the surface (e.g. timing of NO_X emissions, as discussed in *Fishman et al.,* [2008]).

This work will develop best-practice recommendations for the utilization of satellite data for emissions evaluation. In doing so, we advance all three goals of the Texas AQRP research program: (i) To support scientific research related to Texas air quality, especially in the area of emissions inventory development; (ii) To integrate AQRP research with work of other organizations, especially NASA, NOAA, and academic research on satellite applications for air quality; and (iii) To communicate the results of AQRP research to air quality decision-makers and stakeholders, as part of our outreach activities, and leveraging the high value of satellite data for communicating spatial patterns and temporal trends in air quality.

We will develop methods to leverage remote sensing capabilities to improve emission inventories for NO_2 and, to a more limited extent, SO_2. All work will focus on the process-based nature of inventories essential for their use for air quality management.

Satellites measure the column abundance of NO_2 and SO_2, known as the vertical column density (VCD). This column is affected by emissions in the column, the vertical transport of pollutants in the column, other emissions, meteorology, and chemistry. A three-dimensional photochemical grid model (PGM) is the only method that can fully account for all of these processes, and there is a growing record of using satellite data for air quality model evaluation [*Canty et al.*, 2015; *Harkey et al.*, 2015; *Kemball-Cook et al.*, 2015; *Karambelas et al.*, 2018]. Although using a PGM represents the "gold standard" for satellite evaluation of emissions, this approach is costly and limiting, given the computational and personnel resources required for high-quality PGM simulations. To leverage satellite capabilities even without an atmospheric model, satellite observations of NO_2 and SO_2 have also been directly compared with emissions [e.g. *Jin and Holloway*, 2015; *Montgomery and Holloway*, 2018]. For assessment of specific point sources and urban areas, this approach typically requires meteorological correction factors [*de Foy et al.*, 2015; *Goldberg et al.*, 2019b].

Our analysis will evaluate the TCEQ 2020 modeling emissions inventory in two ways, with: 1) a high-resolution (12 and 4 km) PGM simulation; and 2) meteorological corrections on emissions sources, without a model. Study goals include the validation of the TCEQ 2020 modeling inventory, as well as recommendations and software to support future TCEQ utilization of satellite data for emission evaluation.

All analysis will utilize data from the Tropospheric Ozone Monitoring Instrument (TROPOMI). TROPOMI is polar-orbiting with daily global coverage at a nadir resolution of 7 km × 3.5 km, launched in 2017. The spatial resolution offered by TROPOMI is over 10x higher than any previous gas-monitoring satellite, with the Ozone Monitoring Instrument (OMI; nadir resolution of 13 km × 24 km) offering the next-highest capability. As a polar-orbiting satellite with an afternoon overpass, care must be taken in the interpretation of TROPOMI column retrievals as an indicator of near-surface emissions [*Streets et al.*, 2013; *Goldberg et al.*, 2019b; *Penn and Holloway*, 2020]. TROPOMI provides "snapshots" at the same time each day, except as limited by cloud cover, surface albedo, or instrument errors.

3.0 Objectives

The overarching objective of this work is to support regional evaluation of emissions inventories with satellite data. However, emissions are not directly comparable with the column abundance detected by satellites. To support the appropriate utilization of satellite data for emissions evaluation, we advance and compare existing methods for emissions evaluation:

* Compare satellite data for NO_2 and SO_2 columns with model simulations from the high- resolution WRF-CAMx model, including seasonal and monthly mean difference plots across the 12 km and 4 km modeling domains and in-depth difference analyses for select areas. These plots will include a “zoom in” difference plot over West Texas and New Mexico.

* Evaluate the utility of satellite data for NO_X emissions inventory evaluation, without the use of a high-resolution model

* Evaluate how model-based emissions assessment compares to emissions assessment in the absence of model, finalizing recommendations, software, and algorithms

* Develop best-practice recommendations and software to support future TCEQ utilization of satellite data for emission evaluation

4.0 Task Descriptions

4.1 Task 1: Simulate NO_2 and SO_2 amounts with the high- resolution WRF-CAMx model

We will run the WRF-CAMx model for the 2019 ozone season, March 15 – October 15. Model simulations will be conducted by Ramboll, using an existing high-resolution WRF-CAMx model for 2019 developed for TCEQ (Near Real-Time Exceptional Event Model; NRTEEM) described in *Johnson et al.* [2019]. WRF and CAMx modeling domains at 36, 12, and 4 km are used for the NRTEEM system. The 36 km modeling domain includes all of the continental US and large areas of Central America and Canada; The 12 and 4 km domains are the TCEQ State Implementation Plan (SIP) domains, which are used for other modeling efforts by the TCEQ and Ramboll. Figure 1 shows the 12 and 4 km CAMx modeling domains.

The NRTEEM modeling platform covers a simulation period of March 1 through October 15, 2019 (the first full year for which TROPOMI data are available). Chemical analysis is performed by CAMx v6.50 with the CB6r4 chemical mechanism, with input meteorology calculated by WRF version 3.9.1.1 with GFS 0.25 degree analysis data for initial/boundary conditions. We will update the CAMx modeling emissions inventory to incorporate anthropogenic emissions from the 2020 TCEQ modeling inventory (closest to 2019 available; the 2019 NRTEEM project had used a 2017 modeling inventory), and 2019 hourly CEMS data for power plants that are a focus of our analysis. The 2020 modeling emissions inventory does not include impacts of the social and economic response to COVID-19, which is advantageous for this application since we are modeling the 2019 ozone season. Biogenic emissions for 2019 are calculated from Model of Emissions of Gases and Aerosols from Nature v. 3.1 developed by Ramboll in AQRP project 18-005; (MEGAN; [*Guenther et al.*, 2006]), and fire emissions are from the near- real-time Fire INventory of NCAR (FINN) version 2 (if available from AQRP project 18-022). Figure 2 shows sample hourly NO_2 (left) and ozone (right) concentration maps from the TCEQ NRTEEM modeling system.

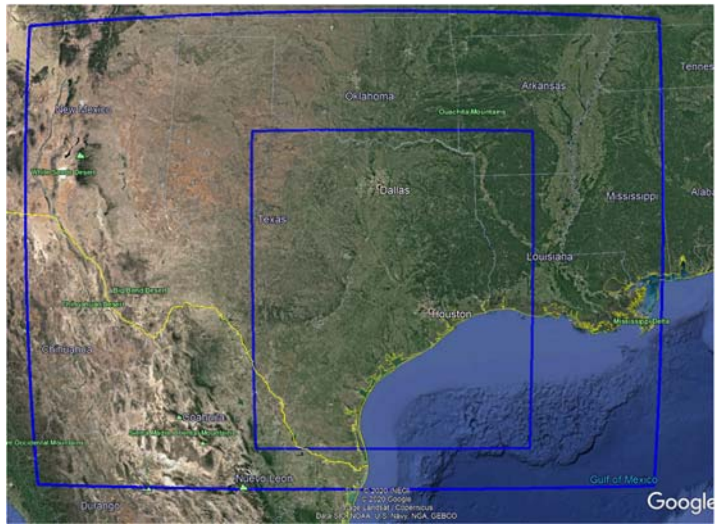

Figure 1. CAMx 12 and 4 km modeling domains used in the TCEQ NRTEEM modeling system developed by Ramboll

We will calculate VCDs from WRF-CAMx in a manner appropriate for comparison with satellite data (vertical integration using TROPOMI averaging kernel; filtering for cloud cover to ensure comparable data availability). This phase of the project involves the development of the 2019 emissions inventory and modeling platform.

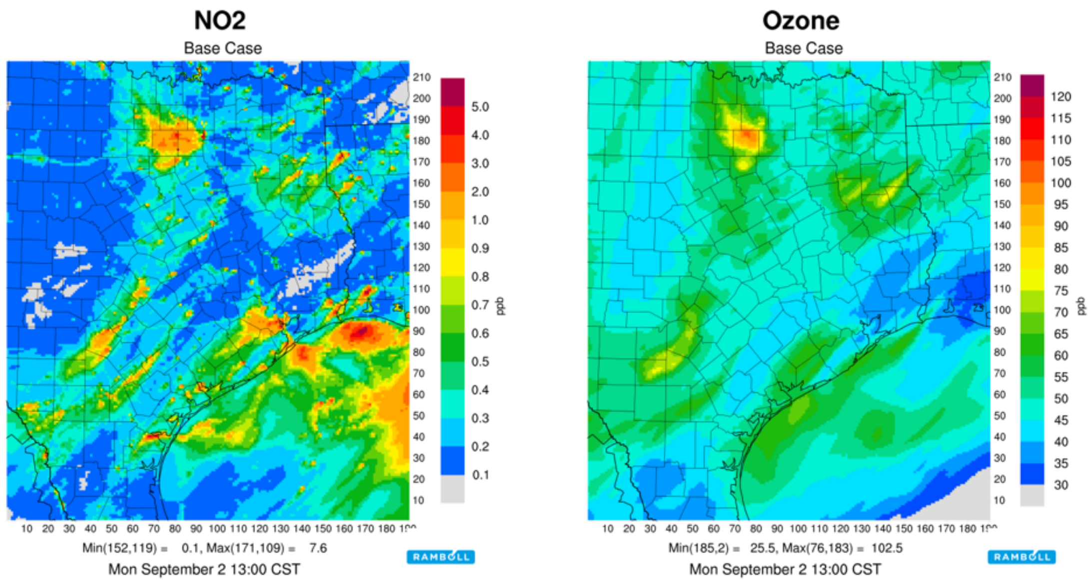

Figure 2. Hourly NO_2 (left) and ozone (right) concentrations for September 2, 2019 13:00 CST from the TCEQ NRTEEM modeling system.

4.2 Task 2: Compare model simulations with TROPOMI and near-surface observations

We will update the publicly-available Wisconsin Horizontal Interpolation Program for Satellites (WHIPS) for use with TROPOMI data. WHIPS was developed by the Holloway Group at the University of Wisconsin—Madison, with NASA Applied Sciences support, and allows users to reformat OMI NO_2, GOME-2 NO_2, OMI HCHO, MODIS aerosol optical depth (AOD), or MOPITT CO to any grid, for direct comparison with model data. WHIPS has been used by Ramboll, the Centers for Disease Control (CDC), NASA, the University of Florida, the California Air Resources Board, and international users. WHIPS regrids the irregular polygons provided by "level-2" data and allocates the data on a specified grid using a variety of available gridding algorithms. In this sense, WHIPS allows users to create custom "level-3" data products for comparison with each other or model data on a common grid. Following this update to WHIPS, TROPOMI data will be gridded for the data analysis period: March 1 through October 15, 2019.

The WRF-CAMx and TROPOMI results will be compared, with agreement with standard performance metrics (e.g. bias, error, r^2) including an evaluation near each source identified in Table 1. In addition, the WRF-CAMx results will be evaluated against ground level observations from EPA and TCEQ, as is currently done for NRTEEM.

4.3 Task 3: Compare satellite data and emissions for power plants and urban areas

Although best-practice, the utilization of a PGM is expensive and time-consuming. Characterizing the value of simpler methods – wherein emissions and satellite data may be directly compared – offers the potential for TCEQ to perform emissions evaluation with satellite data analysis over multiple years and/or considering multiple emission scenarios at a greatly reduced cost.

There are a number of methods that can be used to directly compare emissions and satellite data, even without a model. These range from direct comparison of temporal and spatial emissions patterns [e.g. *Montgomery and Holloway*, 2018], to more sophisticated methods that approximate the effects of meteorology and chemistry, even without the use of a three-dimensional model. As a first step in our analysis, daily TROPOMI NO_2 data will be compared with NO_X emissions, to assess agreement in the absence of meteorological corrections.

Daily TROPOMI NO_2 will also be compared to emissions using the most advanced method, appropriate for power plants and large cities, which considers the statistical fit of the effective NO_2 plume decay over time. This approach was originally proposed by *Beirle et al.* [2011] involves the statistical fitting of satellite-observed NO_2 plumes to an exponentially modified Gaussian function. We will apply a modification of this approach, as presented in *Goldberg et al.* [2019]. This methodology will be implemented by Dr. Goldberg as a consultant to our study, wherein daily plumes from TROPOMI will be mapped onto an x-y grid and then rotated based on the daily wind-direction. As a result, all plumes will be superimposed, increasing the signal-to-noise ratio and generating a more robust fit [*Valin et al.*, 2013; *Lu et al.*, 2015; *Goldberg et al.*, 2019b, 2019a, 2019c] NO_X emissions associated with plumes will be calculated using the following equation:

$$NO_X\ emissions = 1.33\ (\alpha / \tau_{\text{effective}}),\quad where\ \ \tau_{\text{effective}} = x_o / w$$

In this equation, $\tau_{\text{effective}}$ represents the mean effective NO_2 lifetime; x_o represents the fitted decay distance; w represents wind speed; and α represents total burden obtained by the exponentially modified Gaussian fit. NO_2 is converted to NO_X by multiplying by a factor of 1.33 which is typical of the mean column-averaged NO_X/NO_2 ratio in an urban area during the mid-afternoon. This ratio varies in space and time, as discussed in *Goldberg et al.* [2019].

The wind speed and direction needed for these calculations will be taken from the Ramboll WRF simulations at 12 and 4 km, and compared with more widely available re-analysis data (such as ERA-5). Mean near-surface wind speed over all days with valid satellite data will be included.

To evaluate the TCEQ emissions inventory and compare the above methods for satellite application, we examine five power plants and five urban areas. Power plants are chosen because the accuracy of the CEMS data allows us to evaluate methods of controlling for meteorology to link emissions and satellite-derived column densities. Vehicle emissions in urban areas will be compared among cities with emission inventories developed in greater detail (link-based travel demand model) and lesser detail (MOVES defaults) to investigate whether inventory methodology influences the comparison. We consider the following study areas:

a) Five power plants in Texas with significant NO_2 and in some cases SO_2 emissions (proposed sources are in Table 1). These large and relatively isolated point sources have well-constrained emissions measured by CEMS. They will be used evaluated by comparing the PGM and TROPOMI results, as well as to test the methodology of Goldberg et al. [2019] to capture emissions correctly without the use of an atmospheric model. We propose to study sources with differing spatial isolation, surrounding emissions, and fuel. We hypothesize that agreement of CEMS data and satellite data will be enhanced by meteorological adjustment. We expect the agreement to be lower than that achieved with WRF-CAMx, but offering a high level of skill in capturing spatial and temporal emissions variability.

b) Five cities in Texas with significant on-road vehicle contribution to NO_X emissions are selected for evaluation with both the model and no-model approach (see Table 1). These cities are selected to represent three different methodologies for developing mobile source emission inventories: i) link-based travel demand model within Texas (Dallas/Fort Worth and San Antonio); ii) non link-based within Texas (Austin and College Station); iii) default travel demand from the EPA MOtor Vehicle Emissions Simulator (MOVES) (Shreveport). We hypothesize that cities using more advanced travel demand methodologies will show improved agreement with satellite NO_2, both in the WRF-CAMx framework and using the Goldberg et al. [2019a] adjustments. We did not select Houston for evaluation due to its complex meteorology (bay and gulf breezes that can recirculate emissions; Banta et al., 2005) and diverse emissions inventory with many important source sectors.

As resources permit, the satellite-emissions comparison without a 3-D model will be extended to SO_2. This analysis has a higher level of uncertainty, because the TROPOMI retrieval has lower signal-to-noise ratio for SO_2 than for NO_2.

Table 1. Power plants and cities proposed for evaluating the TCEQ emissions inventory.

Power Plant	Comment
Martin Lake	Highest 2018 NOx and SOx in Texas; lignite; rural high biogenic area; major sources ~15 mile distant; (NOx 7241 ton/y; SOx 38273 ton/y)
Limestone	High NOx and SOx; lignite and coal; rural high biogenic area; gas production nearby; (NOx 5676 ton/y; SOx 6009 ton/y)
Oklaunion Power Station	High NOx and moderate SOx; coal; rural moderate/low biogenic area on TX/OK border; (NOx 4495 ton/y; SOx 1469 ton/y). Scheduled to shut down in 2020 but active in 2019.
Sam Seymour	High NOx and moderate SOx; coal; rural high biogenic area; between Austin and Houston; aka Fayette; (NOx 4730 ton/y; SOx 942 ton/y)
Forney Energy Center	Moderate NOx and low SOx; gas; rural outskirts of Dallas; (NOx 782 ton/y; SOx 15 ton/y)
City	
Dallas/Fort Worth	Combined population 2.2 million; Mobile source emissions link-based with city-specific MOVES inputs
San Antonio	Population 1.5 million; Mobile source emissions link-based with city- specific MOVES inputs
Austin	Population 1.0 million; Mobile source emissions non link-based with city- specific MOVES inputs
College Station	Population 0.12 million; Mobile source emissions non link-based with city-specific MOVES inputs
Shreveport	Population 0.19 million; Mobile source emissions non link-based with default MOVES inputs

Power plant emission rates are from EPA Acid Rain Data for the 2018 ozone season

4.4 Task 4: Evaluate mobile emissions assessments performed with and without model

We will evaluate mobile NO_X emissions estimates in the region, comparing model vs. no-model assessment methods, and comparing cities based on their vehicle emissions methodology. We will compare findings from the CAMx-vs-TROPOMI emissions evaluation with a direct inventory-vs-TROPOMI evaluation across the 12 km and 4 km model domains, as well as comparing with the detailed analyses of Dr. Goldberg over select sites.

After determining mobile NO_X emissions biases, we will design a final CAMx simulation that adjusts mobile NO_X emissions to correct these biases. We will then compare performance against the original CAMx simulation by evaluating model results against the same EPA and TCEQ ground level observations as performed in Task 4.1.

A major goal of the analysis will be to evaluate the benefit of using TROPOMI for evaluating emissions with a photochemical grid model and using methods that do not require a full model simulation. We will present recommended methodology for satellite data utilization in the emissions evaluation. Relevant data and software will be made publicly available.

4.5 Task 5: Project Reporting and Presentations

As required, we will provide regular and timely submission of monthly technical reports, monthly financial status reports, and quarterly reports as well as an abstract at project initiation and, near the end of the project, submission of the draft final and final reports, according to the schedule in Section 6.0.

Dr. Holloway, or her designee, will electronically submit each required report to both the AQRP and TCEQ liaisons and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources per http://aqrp.ceer.utexas.edu/. All drafts of planned presentations (such as at technical conferences), or manuscripts to be submitted for publication resulting from this project, will be provided to both the AQRP and TCEQ liaisons per the Publication/Publicity Guidelines included in Attachment G of the subaward.

Dr. Holloway will lead reporting activities with assistance from Ramboll and her team at the University of Wisconsin – Madison. Other deliverables, such as attendance and presentation at AQRP data workshop, submissions of presentations and manuscripts, and submission of project data and associated metadata to the AQRP archive, will be provided according to the schedule in Section 6.0. Project data to be submitted to the AQRP archive will include 12 km x 12 km and 4 km x 4 km gridded NO_2 and SO_2 data from TROPOMI over the study domain and period. Updated WHIPS software to support future model-satellite comparisons will be made available on a public Python distribution platform (e.g. github).

5.0 Project Participants and Responsibilities

Dr. Tracey Holloway will lead the project as Principal Investigator, coordinate collaboration with Ramboll, and supervise the University of Wisconsin – Madison research team. Mr. Jeremiah Johnson will serve as co-Principal Investigator and lead the Ramboll modeling team. Dr. Monica Harkey will support the comparison of gridded TROPOMI data for summer 2019 with the WRF-CAMx model results from Ramboll. A Research Intern will update WHIPS and work with Ramboll and Dr. Goldberg on all TROPOMI data processing. The Information Processing Consultant will support data transfer, file sharing, data archiving, and advanced software needs. An undergraduate student for one summer will support the updating of the WHIPS software to include TROPOMI.

6.0 Timeline

ID	Name	2020							2021									
		J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
1	Modeling	X	X	X	X	X	X											
2	Satellite data		X	X	X	X	X	X										
2	Model analysis						X	X	X	X								
3	Emissions data processing	X	X	X														
3	Direct satellite comparison		X	X	X													
3	EMG satellite comparison					X	X	X	X									
3	Optional SO_2 analysis								X	X	X	X	X					
4	Mobile Inventory Methods			X	X													
4	Modeling									X	X	X	X					
4	Methods Recommendation											X	X	X				
5	Technical Reports	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
5	Financial Reports		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	Quarterly Reports		X			X			X			X			X			X
5	Final Report															X		
5	AQRP Workshop															X		

7.0 Deliverables

AQRP requires certain reports to be submitted on a timely basis and at regular intervals. A description of the specific reports to be submitted and their due dates are outlined below. One report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI will submit the reports, unless that responsibility is otherwise delegated with the approval of the Project Manager. All reports will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. Report templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed.

Abstract: At the beginning of the project, an Abstract will be submitted to the Project Manager for use on the AQRP website. The Abstract will provide a brief description of the planned project activities, and will be written for a non-technical audience.

Abstract Due Date: Friday, July 31, 2020

Quarterly Reports: Each Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Microsoft Word file. It will not exceed 2 pages and will be text only. No cover page is required. This document will be inserted into an AQRP compiled report to the TCEQ.

Quarterly Report Due Dates:

Report	Period Covered	Due Date
Quarterly Report #1	May, June, July 2020	Friday, July 31, 2020
Quarterly Report #2	August, September, October 2020	Friday, October 30, 2020
Quarterly Report #3	November, December 2020, January 2021	Friday, January 29, 2021
Quarterly Report #4	February, March, April 2021	Friday, April 30, 2021

Quarterly Report #5	May, June, July 2021	Friday, July 30, 2021
Quarterly Report #6	August, September, October 2021	Friday, October 29, 2021

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP FY20-21 MTR Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start - June 30, 2020	Wednesday, June 10, 2020
Technical Report #2	July 1 - 31, 2020	Friday, July 10, 2020
Technical Report #3	August 1 - 31, 2020	Monday, August 10, 2020
Technical Report #4	September 1 - 30 2020	Thursday, September 10, 2020
Technical Report #5	October 1 - 31, 2020	Friday, October 9, 2020
Technical Report #6	November 1 - 30, 2020	Tuesday, November 10, 2020
Technical Report #7	December 1 - 31, 2020	Thursday, December 10, 2020
Technical Report #8	January 1 - 31, 2021	Friday, January 8, 2021
Technical Report #9	February 1 - 28, 2021	Wednesday, February 10, 2021
Technical Report #10	March 1 - 31, 2021	Wednesday, March 10, 2021
Technical Report #11	April 1 - 30, 2021	Friday, April 9, 2021
Technical Report #12	May 1 - 31, 2021	Monday, May 10, 2021
Technical Report #13	June 1 - 30, 2021	Thursday, June 10, 2021
Technical Report #14	July 1 - 31, 2021	Friday, July 9, 2021

DUE TO PROJECT MANAGER

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (RoseAnna Goewey) by each institution on the project using the AQRP 20-21 FSR Template found on the AQRP website.

FSR Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start - June 30	Wednesday, July 15, 2020
FSR #2	July 1 - 31, 2020	Friday, August 14, 2020
FSR #3	August 1 - 31, 2020	Tuesday, September 15, 2020
FSR #4	September 1 - 30 2020	Thursday, October 15, 2020
FSR #5	October 1 - 31, 2020	Friday, November 13, 2020
FSR #6	November 1 - 31, 2020	Tuesday, December 15, 2020
FSR #7	December 1 - 31, 2020	Friday, January 15, 2021
FSR #8	January 1 - 31, 2021	Monday, February 15, 2021
FSR #9	February 1 - 28, 2021	Monday, March 15, 2021
FSR #10	March 1 - 31, 2021	Thursday, April 15, 2021
FSR #11	April 1 - 30, 2021	Friday, May 14, 2021
FSR #12	May 1 - 31, 2021	Tuesday, June 15, 2021
FSR #13	June 1 - 30, 2021	Thursday, July 15, 2021
FSR #14	July 1 - 31, 2021	Friday, August 13, 2021
FSR #15	August 1 - 31, 2021	Wednesday, September 14, 2021
FSR #16	Final FSR	Friday, October 15, 2021

DUE TO GRANT MANAGER

Draft Final Report: A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. It will also include a report of the QA findings.

Draft Final Report Due Date: Monday, August 2, 2021

Final Report: A Final Report incorporating comments from the AQRP and TCEQ review of the Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources.

Final Report Due Date: Tuesday, August 31, 2021

Project Data: All project data including but not limited to QA/QC measurement data, metadata, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion (September 20, 2021). The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information. It will also include a report of the QA findings.

AQRP Workshop: A representative from the project will present at the AQRP Workshop in the first half of August 2021.

Presentations and Publications/Posters: All data and other information developed under this project which is included in **published papers, symposia, presentations, press releases, websites and/or other publications** shall be submitted to the AQRP Project Manager and the TCEQ Liaison per the Publication/Publicity Guidelines included in Attachment G of the Subaward.

8.0 References

Banta, R.M., C.J. Senff, J. Nielsen-Gammon, L.S. Darby, T.B. Ryerson, R.J. Alvarez, S.P. Sandberg, E.J. Williams, and M. Trainer, 2005: A Bad Air Day in Houston. *Bull. Amer. Meteor. Soc.*, 86, 657–670, https://doi.org/10.1175/BAMS-86-5-657.

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